THE INFLUENCE OF REAR LOADING ON THE PROTECTION OF CHILD CAR OCCUPANTS IN CHILD RESTRAINTS

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ABSTRACT

The risk of injury to child car occupants can be markedly reduced by their use of appropriate child restraints. These can be child seats with their own integral harness, child booster seats or booster cushions in association with adult seat belts or, if the child is old and large enough, by the use of adult seatbelts alone. However, the protection afforded can be negated if there is significant loading to the child and restraint through the car seat backrest. This paper describes analyses of accident data to demonstrate the occurrence of this effect in field accidents and presents the results of dynamic tests performed to explore the effect on different restraint types of limiting the load intrusion from the rear. Results of tests with child seats with integral harnesses show that head forward excursion is the main concern, the R44 limits being impossible to meet if the seat back is allowed to move as far forward as the R-point. Where the child is restrained by the adult belt, belt forces in excess of the injury tolerance for adults were exceeded, raising to very high levels for backrest movement up to 150mm ahead of the R-point.

INTRODUCTION

This paper reports on a study to investigate the effect that seat back motion has on the risk of injury to children restrained in the rear seat of vehicles, in a range of different child restraint types. Accident investigation showed that children are being injured as a result of luggage, carried in the rear of vehicles, loading the rear seat back onto the child restraint or the child. A dynamic test programme was designed to investigate how the children were being loaded and whether recommendations could be made on how to reduce this loading. The paper discusses some of the accidents involving luggage loading to children and reports on the subsequent dynamic sled testing designed to investigate the effects of luggage loading to children in different restraint types when limiting the translation of the vehicle seat back.

Accident Investigation

TRL has recently initiated a study of serious injuries to restrained children between the years 1985 and 1995. Within a sample of 230 there have been some instances of serious injuries attributed to loading through a distorted vehicle seatback. The mass of any objects in the luggage compartment was not recorded in this data base. Examples are given below.

Example 1

The car involved had a front impact with another car. It was a 12 o'clock direction of force with three quarters overlap. There was large deformation of the vehicle rear seat back but no failure of the latches. A six year old girl was restrained in a booster seat by the three point adult belt in the rear right side seat. She was seriously injured with head and chest injuries. A three year old boy was restrained in a child seat on the rear left side and he suffered serious head injuries. The injuries to both children were attributed to loading from the seat back.

Example 2

The car involved had a front impact with another car. It was an 11 o'clock direction of force with a half overlap on left side. The 50/50 split rear seat back failed due to luggage loading. A six year old boy was restrained in the rear left position. He suffered a fatal fracture dislocation of the upper cervical spine and a ruptured spleen. A two year old girl was restrained in the centre rear position. She was fatally injured with asphyxia due to crushing of the chest. A four year old girl was restrained in the rear right position and suffered serious head injuries.

Example 3

This was a frontal impact into the side of another car. It was a 12 o'clock direction of force with a full overlap. The luggage distorted the lower section of the rear seat back. An eleven year old girl was restrained by the adult belt in the rear seat. She was seriously injured with a torn liver and spleen.

Example 4

The car was involved in a side swipe with a transit van. The latch failed on the split rear seat back. A two year old boy was restrained in a child seat in the rear right position of the car. He suffered fatal injuries to the head. The seat back loaded the child seat causing it to translate forwards and the child's head struck the deformed B pillar.

Example 5

The car involved had a front impact with a heavy goods vehicle. It was a 10 o'clock direction of force with about two thirds overlap of the car. The rear seat back deformed but there was no failure of the latches. An eleven year old girl was restrained by the lap belt in the rear right seat. She was fatally injured with fractured ribs, internal abdominal injuries and fracture dislocation of T9. The child folded over the lap belt and was subjected to loading from behind.

Any child safety package should address the problem of rear seat strength as any improvements in restraint design could be negated by excessive loading from the vehicle seat back.

The introduction of the test procedure to protect occupants against displacement of luggage loading within ECE Regulation 17 was introduced in 1998. Since August 2000 all new car models have had to meet the requirements, and from August 2002 all new cars will have to meet the requirements, which would be expected to influence the incidence of such cases.

Sled testing

The accident studies showed that injuries were occurring when luggage from the car boot of the vehicle was loading the rear seat back onto the occupant. The dynamic test programme was designed to investigate the effects of luggage loading to children in different restraint types when limiting the translation of the vehicle seat back. The ECE Regulation 17 'Approval of Seats, Anchorages and Head Restraints', includes a dynamic test to evaluate the strength of the seat back and latches of the vehicle seat backrest. During this test the forward contour of the seat backrest structure is permitted to translate forwards to a vertical plane passing through a point 150mm ahead of the R point of the vehicle seat. The test conditions for this study allowed translation of a loaded seat backrest structure up to this plane or to an alternative limit of a vertical plane passing through the R Point of the vehicle seat. For comparison, tests were also carried out with no translation of the vehicle seat back.

Test Facility

The Dynamic Restraint Test Facility (DRTF), at TRL Limited, was used for the test programme. The DRTF consists of a rail mounted sled which is accelerated by elastic cords and decelerated by polyurethane deceleration tubes and olives. In this instance, the impact velocity of the sled for all tests was 50 km/h. and the deceleration pulse was that specified for frontal impacts in ECE Regulation 44. The facility was designed to be particularly suitable for routine dynamic testing of restraint systems and has been described in detail elsewhere [1].

Vehicle Environment

The vehicle environment was created by mounting a vehicle body shell onto the test sled. ECE Regulation 17 specifies the use of a loose mass of 36kg in the vehicle boot to represent luggage when testing the strength of the seat back and latches. To investigate the effect of loaded seat back motion, rather than latch strength, a steel plate with a mass of 36kg was attached to the rear of the rear seat back. Heavy duty wires were attached to the backrest to allow controlled forward translation of the seat back. Although this does not accurately reflect the failure through distortion expected in accidents, it does provide the controlled impact environment, simulating the accident condition, necessary for this evaluation programme. The full test arrangement is shown in Figure 1

Figure 1. Test set up

Child restraint systems

Four child seat types were used for each of the three vehicle seat back positions; a conventionally attached safety seat with integral harness, an ISOFix attached safety seat with integral harness and a top tether, a conventionally restrained booster seat and a conventionally restrained booster cushion. New child seats, seat belt webbing and buckles were used for each test.

Although heavy duty wires were used to restrain the backrest from translating further forward than the prescribed limits, it was expected that the child restraint and dummy would also inhibit the full motion of the seat back.

The test parameters that were recorded were sled acceleration, dummy head accelerations, chest accelerations and adult lap and diagonal belt loads. The motion of the dummy and CRS were recorded using

high-speed cine equipment. This was analysed to establish dummy head and child seat excursion.

RESULTS

Head Excursions

The head excursions are shown in Figure 2. The chart shows the head excursions for all seat types. They are grouped into two main sections; safety seats and booster seats. The labels on the x-axis show how the safety seats were attached to the vehicle, and identify the different types of seat used for the booster type systems. Each bar of the graph identifies how far forward the vehicle seat back was allowed to travel and the maximum dummy head excursions. The red line shows the 550mm R44 head excursion limit.

The 3pt belt attached safety seat exceeded the R44 head excursion limit of 550mm by 23% when the seat back was allowed to translate up to the R plane under loading, and by 28% when the seat back motion was limited to 150mm beyond the R plane. The 3 pt ISOFix attached safety seat and the booster systems kept within the R44 limits for head excursion.
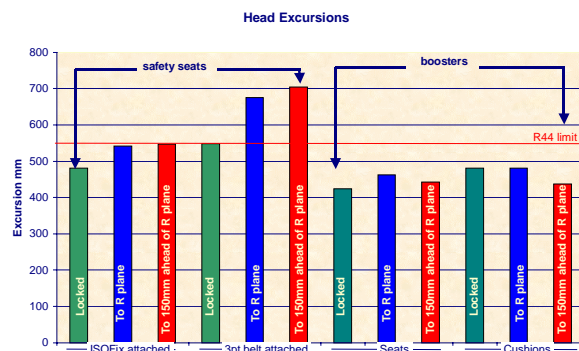

Figure 2. Dummy Head Excursions

The 3pt belt attached safety seat had much greater head excursions because the whole seat was driven forward and then the dummy also moved forward within the safety seat harness. In comparison the booster seat also moved forward with the seat loading, but the dummy was held into the booster seat between the displaced rear seat back and the adult belt. The seat back motion did not reach the maximum permitted, when free to translate to 150mm ahead of the R point plane, due to the adult belt restraining both the dummy and child restraint. There was less forward motion of the 3 pt ISOFix attached seat than the conventionally attached safety seat, so that when the dummy moved forward within the integral harness the head excursions were still within the R44 limit.

Chest Accelerations

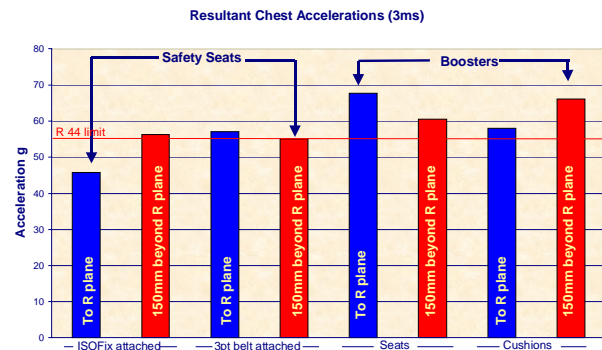The dummy chest accelerations are shown in Figure 3.

Figure 3. Dummy 3ms Chest Resultant Acceleration

The chart shows the 3ms resultant chest accelerations for all seat types. They are grouped into two main sections; safety seats and booster seats. Each bar of the chart identifies how far forward the vehicle seat back was allowed to travel and the maximum dummy resultant chest accelerations for each of the test conditions. The red line shows the 55g R44 3ms resultant chest acceleration limit.

When the rear seat back was limited to translation to the R plane, the dummy chest accelerations in the ISOFix attached safety seat stayed within the R44 limit. All other seats went over the limit. However the safety seats performed better than the booster systems, and the dummy accelerations only went over the R44 limit by up to 4% during testing. The booster systems went over the R44 limit by 20% and 23%. This is because the dummy had greater interaction with the vehicle seat back with this type of restraint.

Diagonal Belt Loading

The chest accelerations recorded by the dummy are not a good indication of chest crushing so belt loading was measured to give an indication of crush injuries. Figure 4. shows the results for the diagonal belt loading, grouped into two main sections; safety seats and booster seats. The adult belt was not used with the ISOFix system. Each bar of the chart identifies peak tension in the diagonal belt for each condition. The green line shows the loading when there is a greater than 50 per cent chance of clavicle injury to adults [2]. The red line shows the loading when there is a greater than 50 per cent chance of internal chest injuries to adults [2]. The blue line shows when there is greater than 50 per cent chance of thoracic injury in more elderly adults [3].
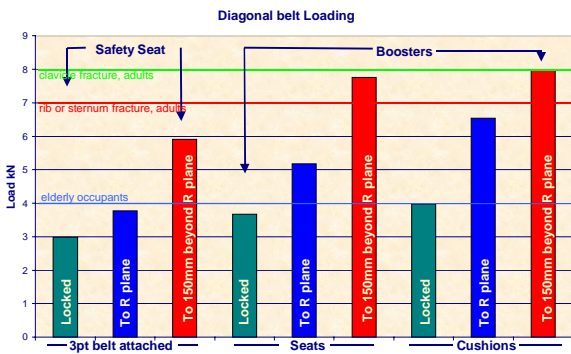
Figure 4. Diagonal belt loading

The loading to the diagonal belt used to attach the safety seat to the vehicle has been included to show how the loading increases as more translation of the rear seat back is allowed. However the diagonal belt was used to attach the seat to the vehicle and not to restrain the dummy so the loadings would not be transferred to the child. The dummy was restrained by the integral harness of the safety seat.

With the booster type systems the loading of the diagonal part of the adult belt would have a direct effect on the child.

The loading in the diagonal of the adult belt, restraining both the dummy and the booster seat, when the rear seat back was locked was below 4 kN. However with the seat back motion limited to translation to the R plane the belt loading increased by 41 per cent to more than 5kN, and when the rear seat back was allowed to travel to 150mm ahead of the R plane the diagonal belt loading increased by 117 per cent to more than 7.5kN.

The loading in the diagonal of the adult belt, restraining the dummy on the booster cushion, when the rear seat back was locked was just under 4 kN. However with the seat back motion limited to translation to the R plane the belt loading increased by 65 per cent to more than 6.5kN, and when the rear seat back was allowed to travel to 150mm ahead of the R plane the diagonal belt loading increased by 100 per cent to just under 8kN.

Lap Belt Loading

Figure 5. shows the loading to the lap belt for the booster type systems. They are grouped by the booster seat results and booster cushion results. Each bar of the chart shows the peak lap belt force for each test condition.

The loading to the lap belt that was round the dummy and the booster seat was 1.3kN when the vehicle rear seat back was locked. This increased by 65 per cent when the seat back was allowed to translate forward to the R point and when it was allowed to translate 150mm beyond the R point. The loading to the lap belt that was
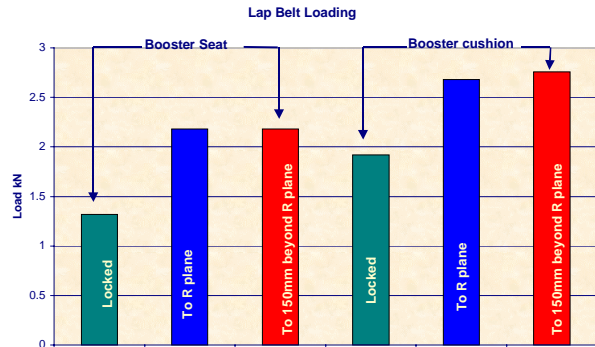

Figure 5. Lap belt loading

round the dummy and the booster cushion was 1.9kN when the vehicle rear seat back was locked. This increased by 40 per cent to 2.7kN when the seat back was allowed to translate forward to the R point and by 44 percent to 2.8kN when it was allowed to translate 150mm beyond the R point.

DISCUSSION

Child Seats

In child seats, the child is restrained by the integral harness or impact shield. For these restraints, the influence of extra forward motion of the back rest will not be through greater loading to the child but through extra forward excursion due to loading to the child seat itself. Figure 2 shows that the forward excursion of the child's head is greatly increased when the backrest translates. For the 150mm forward of the R-point condition, the forward motion is increased by 150mm for the adult belt restrained child seat. This is likely to have a large effect on the risk of head contact and hence head and neck injuries.

The forward excursion of the ISOFix and top tether attached integral harness child seat was increased but by a much smaller amount.

Booster Cushions and Booster seats

For these restraints the head excursion was actually reduced. But this was only due to the dummy being

compressed between the backrest and the adult belt, which kept the dummy more upright.

The main problem for children in these restraints is the extra force applied to the child's torso through this loading.

Increased diagonal belt loading, caused by the rear seat motion, onto a child would greatly increase the likelihood of injury. The likely hood of injury increased with the translation to the R-point condition, but the results were considerably worse for the 150mm forward of the R-point condition.

Injury risk functions are not available for children so it has been necessary to use adult information to put these measurements into perspective. This is not ideal but some conclusions can be drawn. Previous research at TRL [2] investigated injury tolerance levels in adults, for shoulder belt tension. The probability of clavicle injury remains low up to around 6kN and then increases sharply to around 50 per cent by 8kN. With belted adult car occupants rib fracture was always evident when there were internal injuries to the chest. Table 1. shows the percentage of adults likely to suffer internal chest injury, at the belt loading levels that we measured.

A more recent study [3] has called for shoulder seat belt load limitation in vehicles to be set at 4kN in order to protect elderly occupants.

Table 1.

Percentage of adults likely to suffer internal chest injury

Diagonal Belt loading	percentage of adults likely to suffer internal chest injury
4kN	10%
5kN	20%
6.5kN	45%
7.5kN	60%
8kN	70%

The webbing characteristics of seatbelts are designed for adult use. The forces generated for a given extension may be acceptable for an adult but too great for a child to sustain. Under normal circumstances, this is not a problem because the child is much lighter than the adult and would result in a reduced extension and thus a lower force. However, when the child is loaded by a rear seat back loaded with luggage this becomes a problem. Children's bones are softer than those of

adults and it is possible for a child to have internal chest injuries without rib fracture. As the bones of a child are more flexible than those of an adult, a child would crush more easily than an adult between the belt and the seat back, and therefore be likely to suffer greater internal injuries with less belt loading.

With these booster cushion and booster seat restraints, the lap belt loading also was increased and the lap belt applies load directly to the child's pelvis.

The TRL study [2] reported that the incidence of abdominal injury to adults appeared to be insensitive to the variation of lap belt loading when the belt was properly adjusted. However in nearly all cases of abdominal injury there was good evidence that the seat belt had been incorrectly adjusted so that the lap belt was bearing on the soft part of the abdomen rather than the very much stronger pelvic bones during the impact. It is well known that a child's pelvis is not fully fused like that of an adult, and as a result one would expect that the risk of submarining and of child internal abdominal injuries to increase substantially as the loading to the lap belt is increased.

The introduction of the luggage test should result in some improvements from the level provided by the earlier seats in the accident review. However, the sled based study highlights that the potential level of forward movement, of 150mm, permitted by the new test does not offer a meaningful limit to protect children if the car seat moves forward to the extent permitted and the child is loaded with the 36 kg loading.

CONCLUSIONS

- Vehicle rear seat displacement both to the R-point and 150mm beyond the R-point increased the displacement of a conventionally attached safety seat to a level where the dummy head excursion was greater than the limit permitted for regulatory approval of child seats.

- The head excursions in a 3-point ISOFix safety seat are likely to be less than those of a conventionally restrained safety seat in the case of rear loading.

- The seat back motion was less with booster type systems, but this is because the backrest was held back by the child.

- Diagonal seat belt loading increased as more translation of the rear seat back was allowed.

- The loading of the diagonal part of the adult belt had a direct loading effect on the occupant of the booster type system.

- Increased diagonal belt loading, caused by the rear seat motion, onto a child would greatly increase the likelihood of crush type injuries. The results were considerably worse for the 150mm forward of the R-point condition.

- Loading to the lap belt increased substantially when the rear seat back was allowed to translate to the R-point plane, probably increasing the risk of abdominal injuries.

- The potential level of forward movement, of 150mm, permitted by the new test for seat back strength does not offer a meaningful limit to protect children if the car seat moves forward to the extent permitted and the child is loaded with the 36 kg loading.

- Any child safety package should address the problem of rear seat strength as any improvements in restraint design could be negated by weak rear seat backs.

RECOMMENDATIONS

During the ECE Regulation 17 dynamic approval test the vehicle seat back strength is tested with 38kg of luggage. Vehicle seat backs should be strengthened to withstand a higher mass which can be encountered in accidents.

Regulation 17 allows the forward contour of the seat backrest structure to distort forwards to a vertical plane passing through a point 150mm ahead of the R point of the vehicle seat. These findings suggest that at this level chest injury would occur to a child restrained in a booster type system and a child in a safety seat may suffer increased risk head injuries, through increased translation of the child seat. The deformation of the backrest should be limited at least to the vertical plane through the R-point

Children should continue to travel in safety seats for as long as possible before being moved to a booster type system as child seats reduce the risk of crushing from luggage loading.

REFERENCES

1] Hill K J, Roy A P. Simulation of the Effects of Vehicle Impacts on Restrained Child Occupants - Part A: A description of the KL/MP Test facility. Journal of the Society of Environmental Engineers 21st March 1982.

2] R.W. Lowne, J.G. Wall. 'A Procedure for Estimating Injury Tolerance Levels for Car Occupants'. Paper No. 760820. Proc. 20th Stapp Car Crash Conference, 1976.

3] J-Y. Foret-Bruno, X. Trosseille, J-Y Le Coz, F. Bendjellal, C.Steyer, T. Phalempin, D. Villeforceix, P. Dandres, C. Got. Thoracic Injury Risk in Frontal Car Crashes with Occupant Restrained with Belt Load Limiter' SAE Paper No. 983166, 1998.